ENGINEERING CASE LIBRARY

ECL 54*

Design of a Mirror Mount at Beckman and Whitley, Inc.

"I'm embarrassed to admit it, but my draftsmen and I recently spent over 12 man-hours in determining the shape of a tiny block of aluminum -- a job that any one of us should have been able to do in just a few hours," said Les Brown, a development engineer at Beckman and Whitley, Inc. "We wasted a considerable amount of time due to the fact that we had all forgotten our descriptive geometry and due to communication problems with one of our machinists."

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*Revised in July 1968 by Richard C. Bourne.

Beckman and Whitley, founded in 1945, was the first company to produce what is now known as a high speed camera. These cameras, which take pictures at the rate of 200 to 200 million pictures per second, are used in research work to photograph events of very short duration such as explosion shock waves. One of the company's cameras, the model 189 Synchronized Framing Camera, is so widely used that the Smithsonian Institute has asked for one for its permanent collection.

Although high speed cameras have continued to be the main product line (B & W is the world's largest producer), the company has diversified into several other areas of instrument design. Among the products that the company presently markets are several types of meteorological instruments, heat flow transducers, and laser devices.

In June of 1963 B & W engineers began a project that diverged considerably from their existing product lines. Working under a contract from the American Broadcasting Company, they developed a 16mm portable television news film camera. The camera incorporated several radically new features, such as continuous film motion, which were based upon B & W's know-how in high speed camera design.

In April of 1965, Mr. Brown was given the job of developing the prototype 16mm camera into a production model. Though the camera had evolved through three prototypes and numerous field tests, Mr. Brown, a former chief engineer at the Mitchell Camera Company, found that most of its parts required extensive redesigning to improve their performance and to make them economical to manufacture.

One such part was a mounting for a mirror that directs some of the image light* into the camera's view finder. The general location of this mounting is

*A beam splitting mirror intercepts the image light prior to its reflection by the mirror under discussion. The beam splitter reflects 75% of the light to the film and transmits 25% to the mirror.

shown in Exhibit 1. The earlier prototypes had employed externally mounted view-finders as shown in Exhibit 2. Exhibit 3 shows, in two views, the desired change of direction of the optical axis (30 degrees above horizontal in the front view, directly upward in the side view). A divergent cone of light enters through the circular area shown in the front view. The mirror must intercept as much as possible of the incident light; Mr. Brown noted that, due to space limitations, imposed by the shape of the camera base plate die casting, all of the image light could not be intercepted. The volume available for the mounting block and mirror is shown in Exhibit 3; this volume is a right prism whose "plan" is seen in the camera side view.

Mr. Brown planned to make his mount a metal block that could be fastened to the locating surface shown in Exhibit 3. This surface would be precisely machined so that it could serve as a guide to locate the block in one dimension. The block would be located further by an integral pin that would fit into a precisely drilled hole in the locating surface.

A front-surface mirror .125 inches thick would be attached to one face of the mounting block with spring clips, and the block would, in turn, be held to the locating surface with two machine screws.

From Mr. Brown's experience in camera design, he knew that it would be necessary to make some adjustments in his optical system to compensate for manufacturing tolerances. Some compensation for minor misalignment could be made by rotating the mirror about the axis of the locating pin. Mr. Brown planned to make any further adjustments by moving other parts of the view-finder optical system.

After studying the problem of determining the shape of the mounting block for a while, Mr. Brown realized that he did not know how to specify the location

of the plane on which the mirror was to be mounted. He consulted with his draftsmen and found that neither of them was able to provide an immediate solution. Two days later, the draftsmen were still looking for an answer.

Mr. Brown explained the problem this way, "I studied descriptive geometry in college, but most camera design involves shapes that appear in true dimensions in orthographic projection. As a result, I'm afraid that I've forgotten the techniques needed to solve this problem."

Mr. Brown estimated that over 12 man-hours were ultimately spent by his draftsmen to produce a workable drawing of the mounting block. The final solution to the problem involved the use of descriptive geometry, but other techniques were tried first. The engineer described to a machinist, with a freehand sketch and words, what was thought to be the desired shape. The machinist proceeded to mill a wooden block from these instructions and, on the second attempt, did produce a block that would cant the mirror at the desired angle. The block did not fill up the available space, as was desired, but it did give the draftsmen an idea of the shape they were trying to define.

After seeing the wood block, the draftsmen prepared the sketch shown as Exhibit 4. This sketch is actually a series of instructions that show some of the steps which would produce the desired part.

The machinist was told verbally to begin with a block of aluminum 1.12 X .93 X .93, set in a milling machine dividing head, and to cut off its front corners as shown in plan view (dotted lines show original outline of block). The resulting shape, as seen in the plan view, is the shape of the surface of the block that will contact the locating surface of the die casting.

The next step was to look at the part from the direction labeled END VIEW FIRST STEP and determine on a milling machine the location of the imaginary

point indicated. This point represents the intersection of the optical axis with the mirror.

The part was to be then rotated 30° counter-clockwise about the axis of rotation. The 30° angle is indicated in FRONT VIEW SECOND STEP. Having rotated the part, the machinist was told to look at it from the end view and face it using the instruction .125 COMPOUND CUT. This cut forms the surface on which the mirror is attached.

The machinist interpreted the drawing and cut a block. The block was not what the draftsmen wanted.

Mr. Brown commented, "None of us knew what the block should look like. Even when we received the part that had been made from the sketch, we had some debate as to whether or not it was correct. We did know the shape of the base of the block from the dimensions of the casting. We also knew, from experimenting with a mirror fastened inside one of the prototype cameras, how we could locate the desired plane of reflection by rotating the block 30° and taking a 45° cut -- this was the basis for the sketch. If we could get one correct block cut using the sketch, we could prepare a production drawing and check its validity by "miking" the block. I think that a model maker could have used our sketch, but unfortunately our machinist was accustomed to working from production drawings."

Later, Mr. Brown discovered that the view labeled END VIEW FIRST STEP showed the wrong shape. "A correctly shaped block could have still been made from the sketch since the indicated cut in that view is the correct one," said Mr. Brown. "However, the incorrect view probably did add to the machinist's confusion."

A production drawing was finally prepared using descriptive geometry techniques relearned from an engineering handbook (Exhibit 5). The part shown in

this drawing is essentially the same as the part which the preceeding sketch intended to show, but it also contains several mounting and locating holes as well as one surface that has been relieved to accommodate a spring clip. This drawing was given to another machinist and the correct part was made from it.

After a cost analysis, Mr. Brown decided to manufacture the production mounting block using investment casting followed by milling of the surface that holds the mirror.

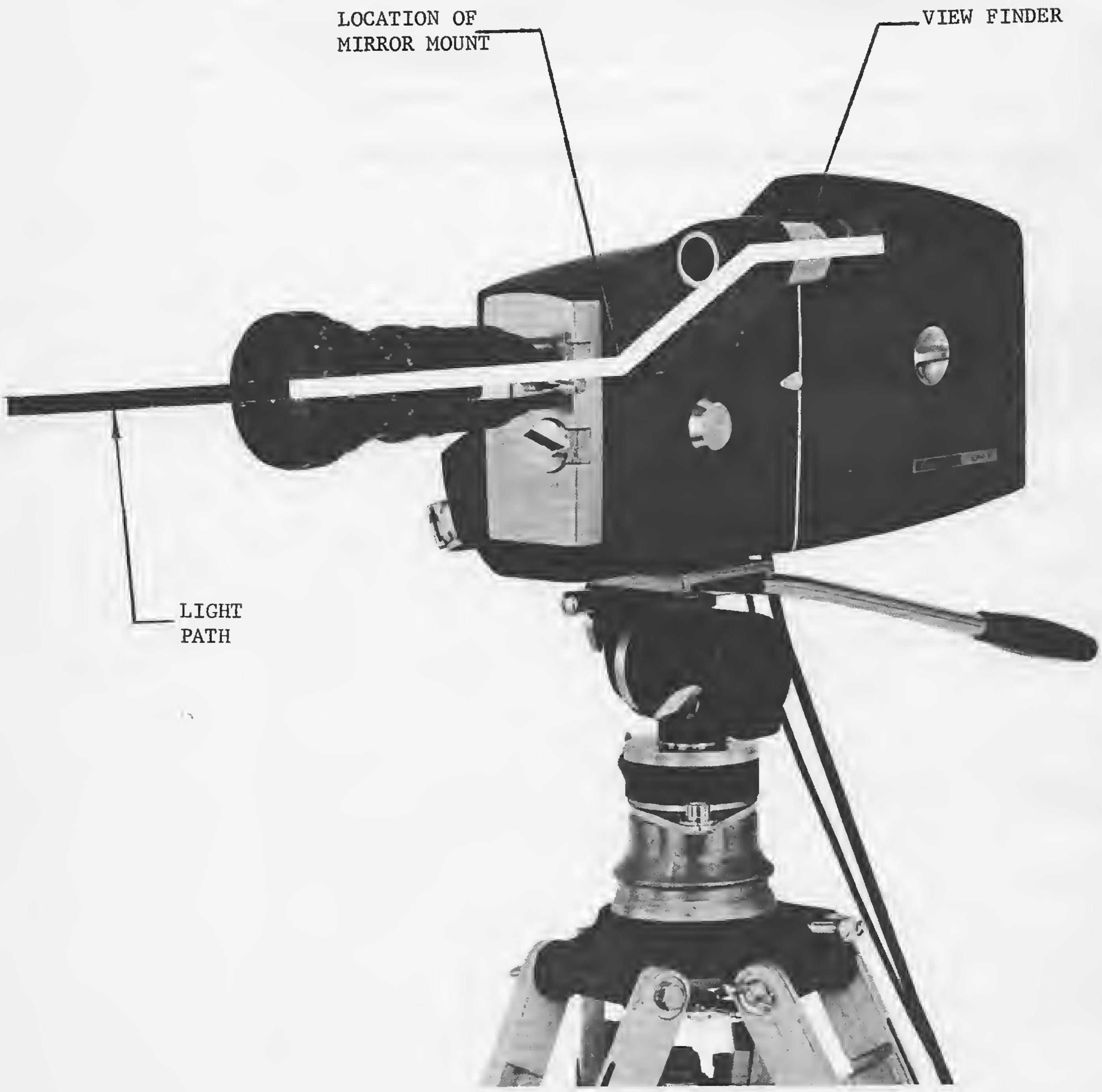
Suggested Assignments

1) Decide which dimensions and/or angles are critical to the proper funcfioning of the block.

2) Design a mirror block to reflect as much as possible of the incident light. To simplify the problem, assume the appropriate surface of the block is coated to reflect light (i.e., mirror is no longer a separate piece).

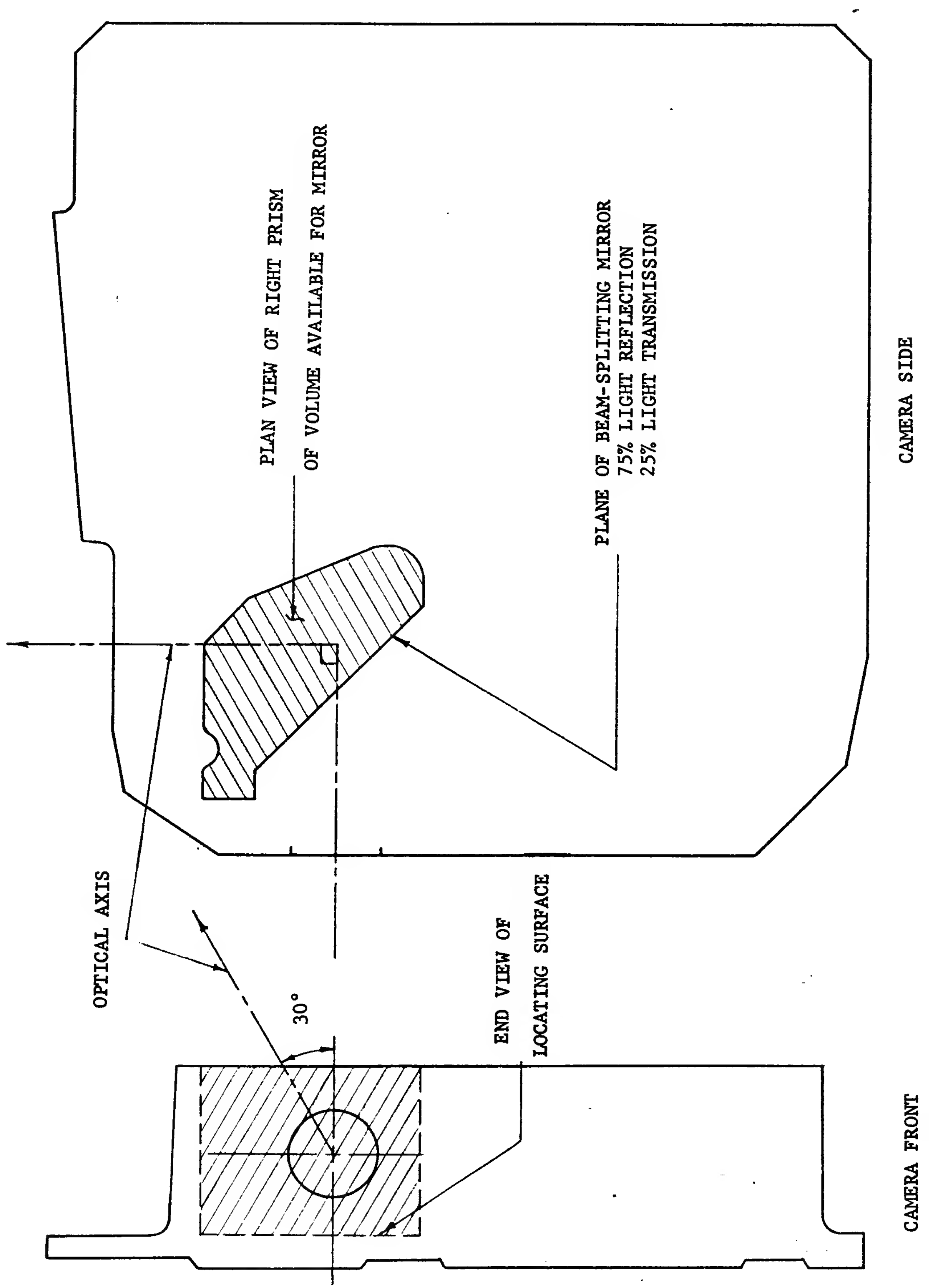
3) Describe how several prototype blocks might be manufactured.

CM-16 CAMERA WITH VIEW FINDER LIGHT PATH INDICATED

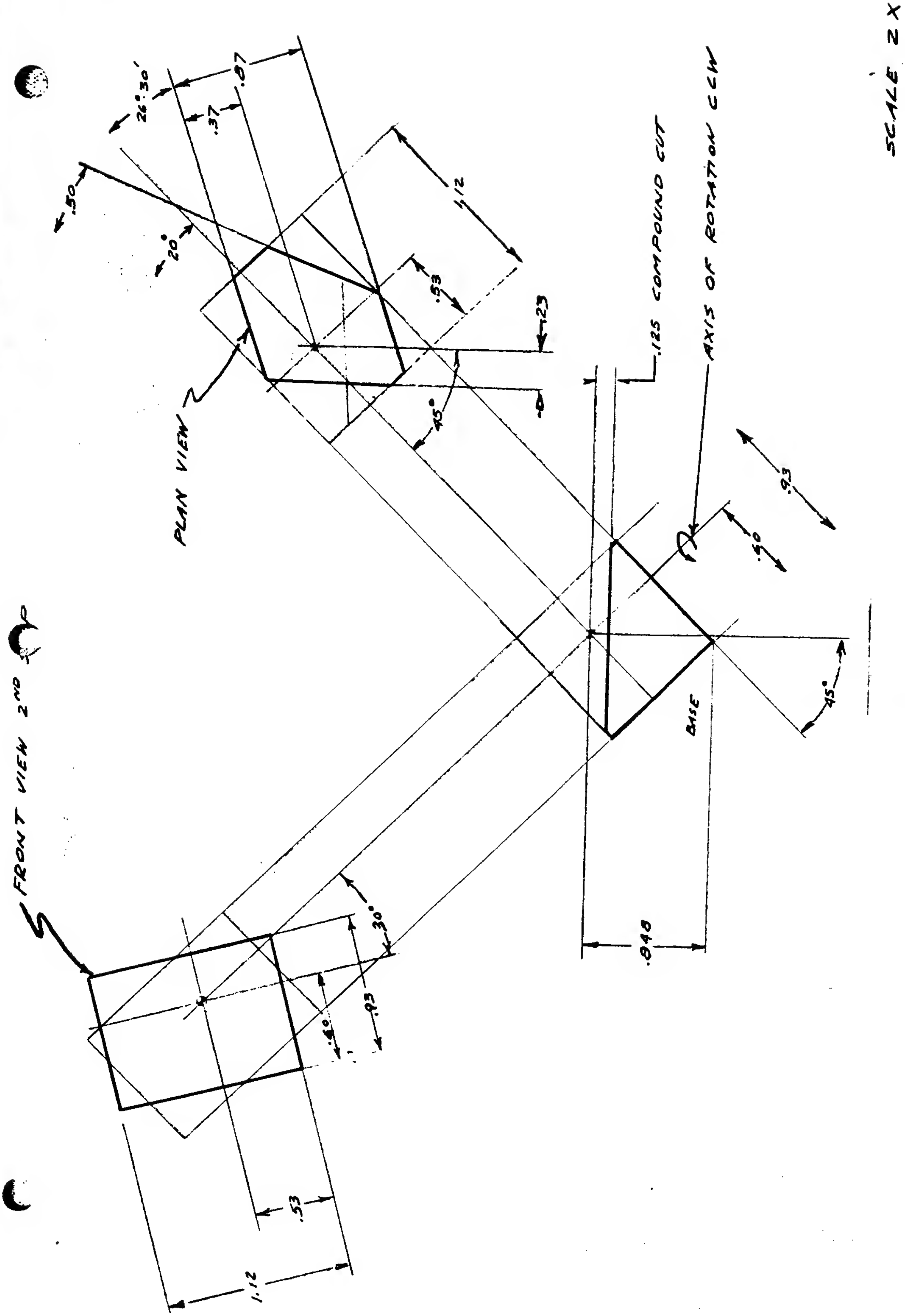


TYPICAL MODE OF OPERATION OF PROTOTYPE CAMERA
(Soundman on the left)

(DRAWING MAY BE SCALED)

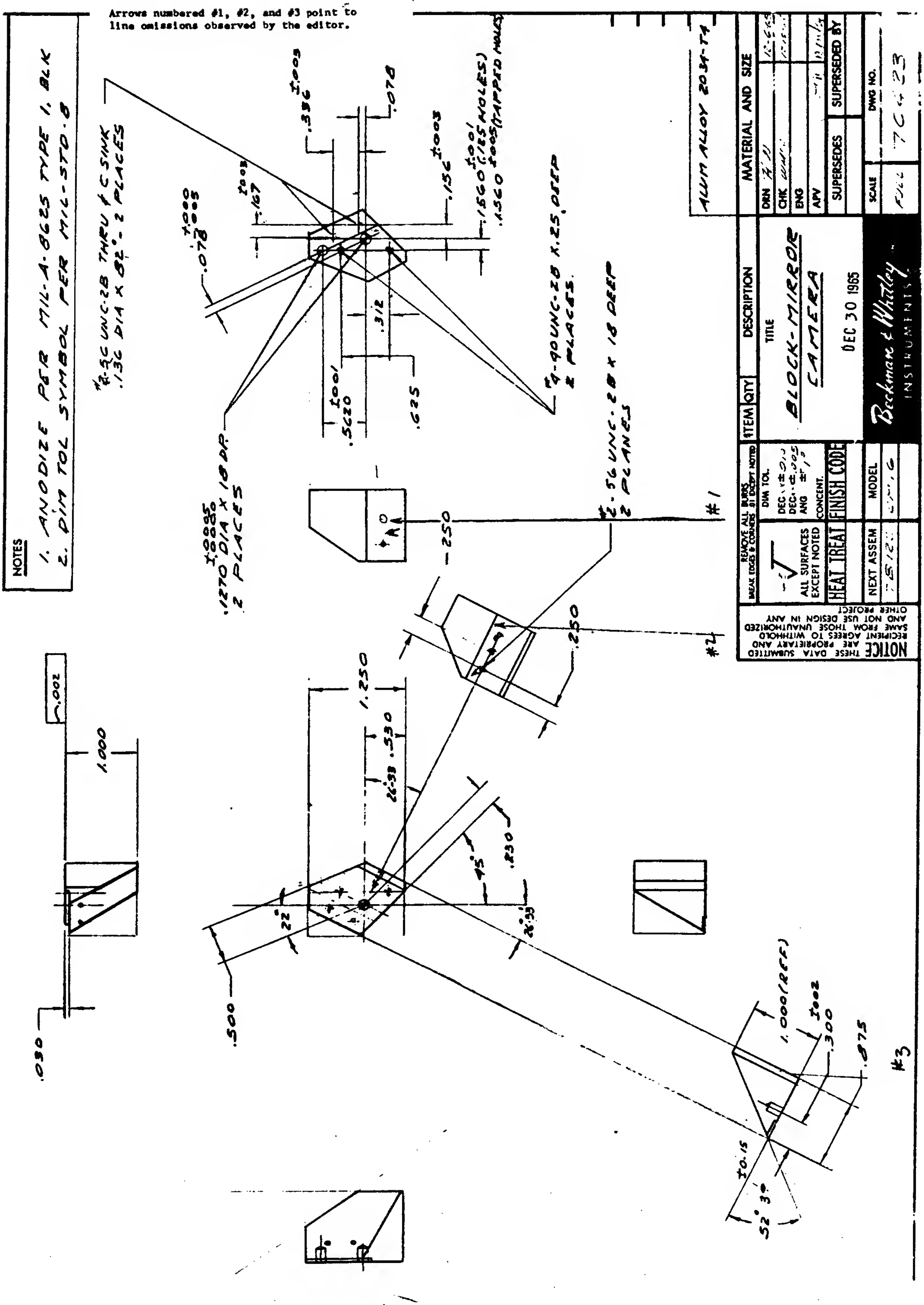


LOCATION OF OPTICAL AXIS RELATIVE TO BASE PLATE CASTING



MOUNTING BLOCK MANUFACTURING SKETCH

Arrows numbered #1, #2, and #3 point to line omissions observed by the editor.



MOUNTING BLOCK MANUFACTURING DRAWING

Instructors' Notes

This case relates a detail problem of descriptive geometry connected with the camera development which is described in ECL 46. Mr. Brown was exceptionally candid in relating the facts of the case. To overcome the temptation of feeling superior to him we remind ourselves that only teachers, kings, and customers are always right. Engineers invariably "iterate" to bring the benefit of hindsight to bear on their work.

ECL 54 is a moderately complex problem in dihedral angles. It will gain interest if it is combined with a discussion of ECL 46.

Assignment I

The purpose of this initial assignment is to impress on the student the desirability of identifying immediately those angles and dimensions (if any) which must be held to close tolerances for the device to fulfill its function. Approaching the problem in this manner enables the designer to satisfy initially the primary requirements, letting secondary criteria influence the remaining aspects of the design.

The function of the mirror is to reflect light at a location and angle proper to be received by another mirror in the system. The position of the mirror surface must be established quite precisely to perform this function. The mirror surface is to be held in the correct orientation via the solidity of the block, which will fasten to the camera at the locating surface.

There are two factors, then which must be controlled very precisely:

1) Location of the point of incidence (0) determined by the positioning pin described by Mr. Brown on page A-2. If located accurately, this pin will always keep the incidence point in the same spot, regardless of the block rotation angle about the pin.

2) Orientation of the mirror surface affected by the angle between the mirror surface and the locating surface (whether the two actually intersect or not) and by the angular position of the block about the pin.

In specifying the block, then, we must describe the locating pin position and the angle between the mirror and the locating surfaces with the closest tolerances. As seen from the tolerances in Exhibit 5 (Beckman and Whitley production drawing), Les Brown et. al. were aware that these were the critical factors.

Assignment II

An accurate mirror block can be designed by successful execution of the following three steps:

1) Determination of mirror surface orientation.
2) Determination of angle between mirror surface and locating surface.
3) Bounding the wedge defined by step 2.

These steps are described in detail in the paragraphs which follow. As is pointed out from time to time in the discussion, there are other ways to proceed in solving this problem. It appears, however, after trying several methods, that the one described here leads to the simplest and most precise block.

1) Mirror surface orientation.

Most students will be aware that, for a light ray striking a mirror surface, the angle of incidence equals the angle of reflection. The incident ray and its reflection determine a plane; the line in this plane which bisects the angle formed by the two rays must be normal to the mirror plane at the point of incidence. We can use the given optical path as incident and reflected rays; by bisecting their included angle (in true view) we can find the mirror normal and thus determine mirror orientation.

Exhibit T-1 shows two ways we may find the normal:

A) Since the camera front view shows the plane of the optical path as a line, an auxiliary view across a fold line parallel to that line will yield a true view of the plane of the optical path. We can locate the normal in

this view and, by assigning lengths to the incident and reflected rays, project the now finite lines back into the previous views in the accustomed manner.

B) A short-cut method uses the same basic technique as 1) above, but requires no anxiliary view. In the front view, reflected ray O-B is true length. In side view, incident ray O-A is true length. If the two true length rays are defined to be of the same length (as was conveniently done in the auxiliary view used for solution 1), then the line A-B contains point N, with A-N equal to N-B.

With the normal thus determined, we know the orientation of the mirror plane.

2) Angle between Mirror Plane and Locating Surface

With the mirror normal determined, there are several ways we could proceed with the design of the mirror block. We could (as did Beckman and Whitley) begin with a right prism whose base fills the designated area in the side view. If the basic prism is projected into an auxiliary view in which the mirror plane appears as a line, the mirror block is determined (see Exhibits T-3, T-4). However, some accuracy is lost with this plan of attack since, to find the critical angle, we must have an end view of line m-n. This new view must be projected from the side view, where m-n is true-length. Because m-n was first found in an auxiliary view projected from the front view, the critical angle must, by this method, be projected through three successive views before appearing as a "true" angle; some loss of accuracy in the constructions cannot be avoided. From the educational standpoint, however, this circular approach is, in itself, a greater drawback to the method than the loss of accuracy. We should seek to determine the critical angle immediately, and can do so with little trouble. And, as seen by comparing Exhibits T-2 and T-4 the preferred method results in slightly greater mirror area on a block of more simple shape.

To find the angle in question, we need a view in which both the locating surface and the mirror surface appear as lines. Since the locating surface appears as a line in the front view, it must also appear as a line in any auxiliary view taken perpendicular to the side view. The mirror plane appears

as a line in any view in which the normal O-N appears in true length. The desired new view can obviously be obtained across a fold line parallel to O-N in the side view. As seen in Exhibit T-2, the critical angle is found to be 52½ degrees. This view also determines the location of the intersection ("trace") of the two planes, line 9-10.

In retrospect, we can see that, had the block been fastened at the back (perpendicular to incoming optical axis O-A) rather than at the side, the design problem would have been still simpler. The trace of the mirror plane on the fastening surface would be perpendicular to O-N in the front view; since O-N lies on O-B in this view, a single auxiliary view across a fold line parallel to O-B gives the entire solution. The problem of locating O-N in the side view would not have been encountered were the block to be fastened on a plane perpendicular to line O-A.

3) <u>Bounding the infinite wedge</u>.

Having determined the critical angle and the location of the "trace" (line 9-10), consider a large wedge, two faces of which intersect at a 52½ degree angle (Exhibit T-5). If we are to cut the block from this large wedge, the line of intersection of these two faces must be aligned on line 9-10 in the side view of Exhibit T-2. We can now use the given constraints to further specify the mirror block.

One restriction is the available width in the camera. The camera wall opposite the locating surface can be constructed in the auxiliary view (Exhibit T-2). Allowing suitable clearance, this determines mirror edge 2-4 parallel to 9-10. We can now arbitrarily choose plane 1-2-3-4 to contain line 2-4 (providing this leaves room for the pin on the locating surface). For convenience this plane has been chosen perpendicular to the locating surface.

Our large wedge has now been reduced in one dimension; it is still very long, but its cross-section has been cut to be identical to the triangle shown in the auxiliary view. We can now apply the second restriction: that of the available space specified in the side view. Maximum mirror area, of course,

will be obtained by conforming remaining block sides to the given outline, as has been done (allowing 1/32" clearance) in Exhibit T-2. A final cut has been made to remove a sharp top corner, which added very little mirror area.

The block has now been completely determined in side view; by projecting into the other two views, we obtain a complete three view drawing of the block. Exhibit T-2 shows the pin about which the block will be rotated for precise adjustment. This pin must be located at the foot of the normal from the locating surface to point O.

Assignment 3

There are, of course, many ways the mirror blocks could be machined. One could proceed as did Beckman and Whitley in their first attempt to cut a prototype block: that is, start with a right prism whose base is shaped to fill the available area on the locating surface (Exhibit 3), then, rotating the block about two axes, make the cut which determines the mirror surface. This approach, however, would seem to affirm the erroneous concept that it is this basic prism which should determine the design. Actually, as stressed earlier, the primary consideration must be the angle between the mirror and locating surfaces.

To manufacture a few prototypes, one might proceed much as suggested in the design approach proposed in assignment two: that is, begin by machining a long wedge of cross-section identical to the triangle of the auxiliary view, Exhibit 2. Parallel oblique cuts should then be made at angle 9-10-1 (116 degrees) to the 52½ degree edge. This action would yield blocks having desired side 10-1-2 and a parallel opposite side, part of which would become surface 5-6-7-8. A further sizable corner cut is made to form surface 3-4-5-6, and the top corner can be trimmed or ground to yield the small surface 7-8-9. The pin position should be located with respect to edge 9-10; distances required to locate P may be found in side view of Exhibit T-2.

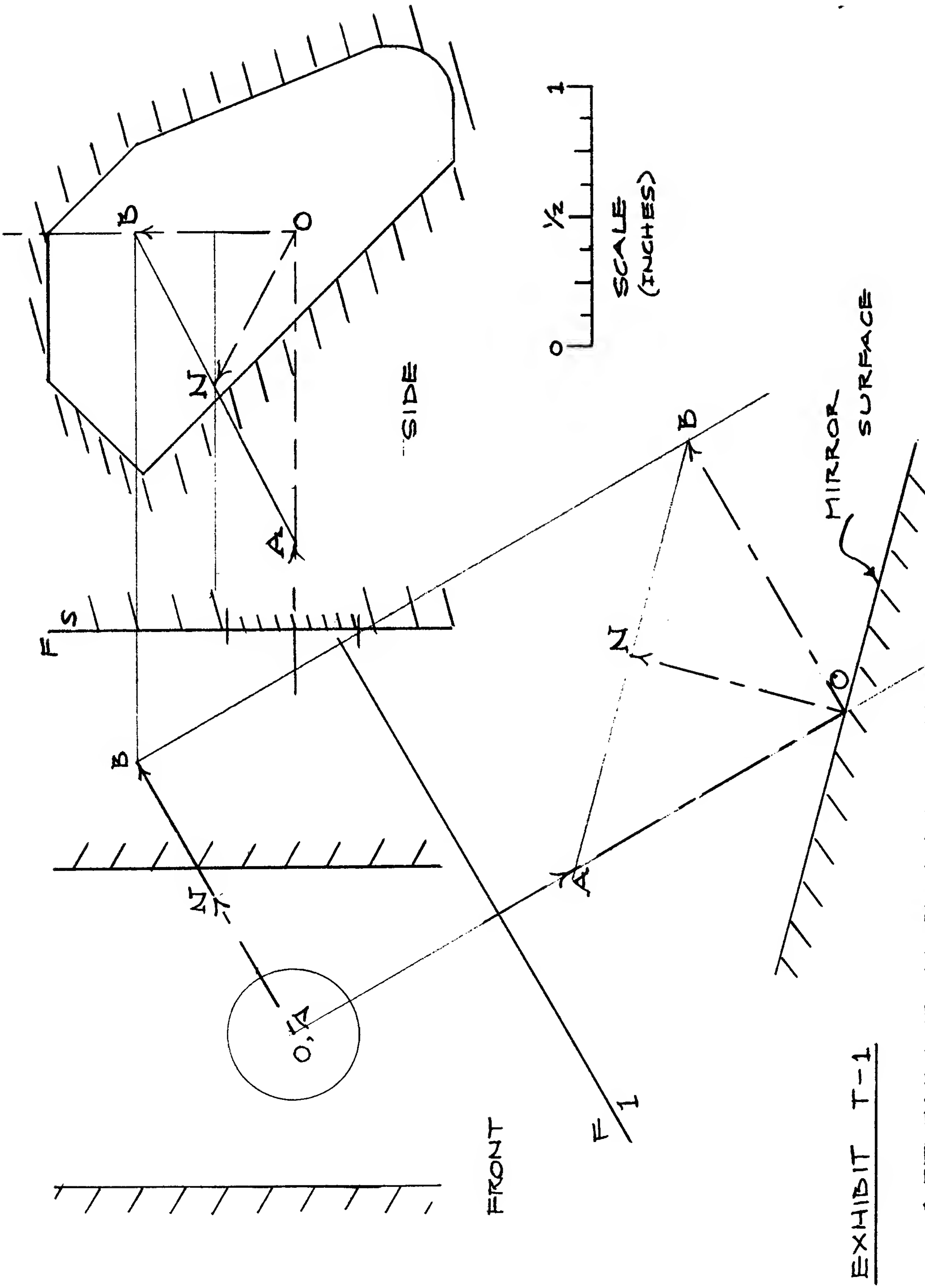


EXHIBIT T-1

DETERMINATION OF MIRROR NORMAL

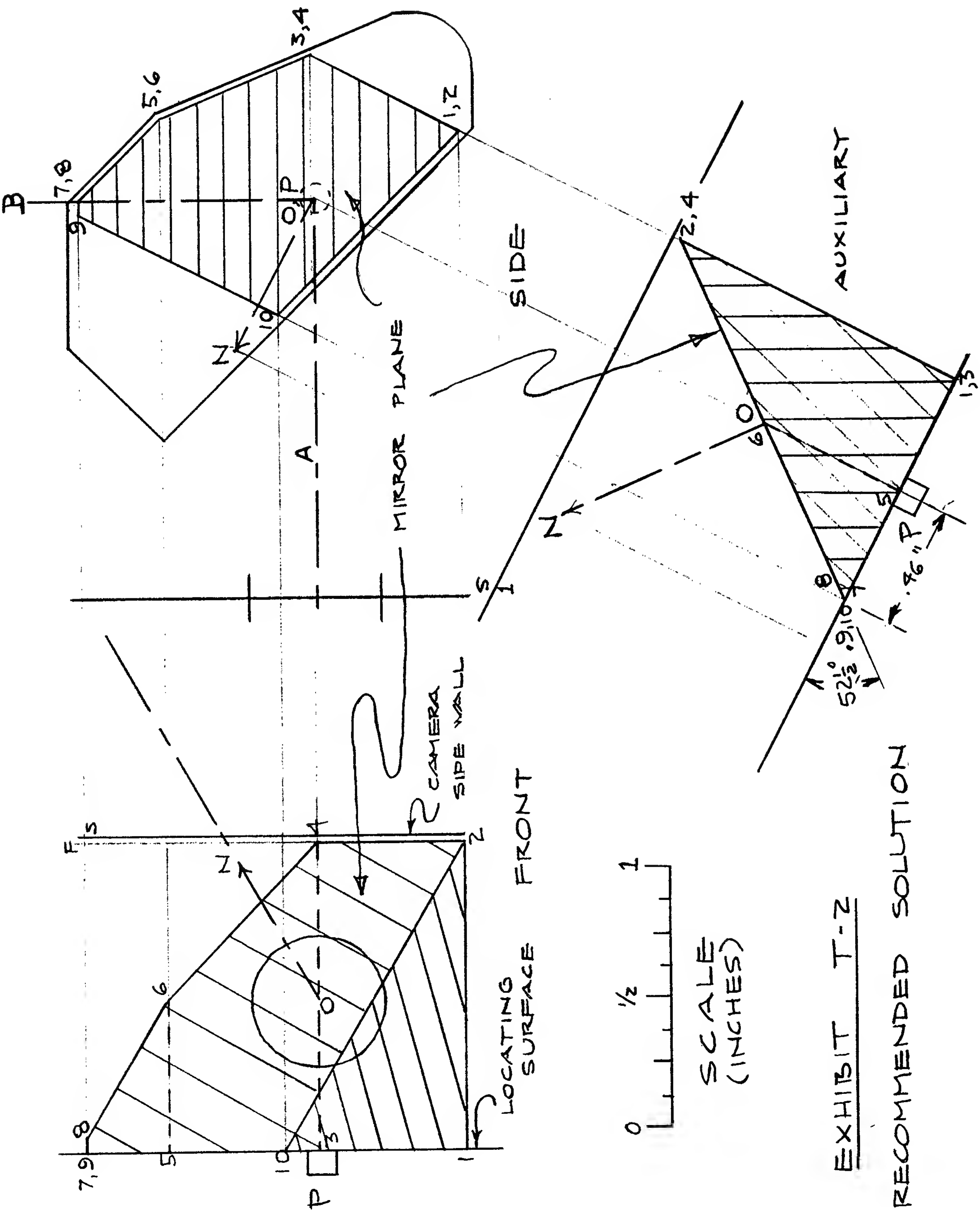


EXHIBIT T-2

RECOMMENDED SOLUTION

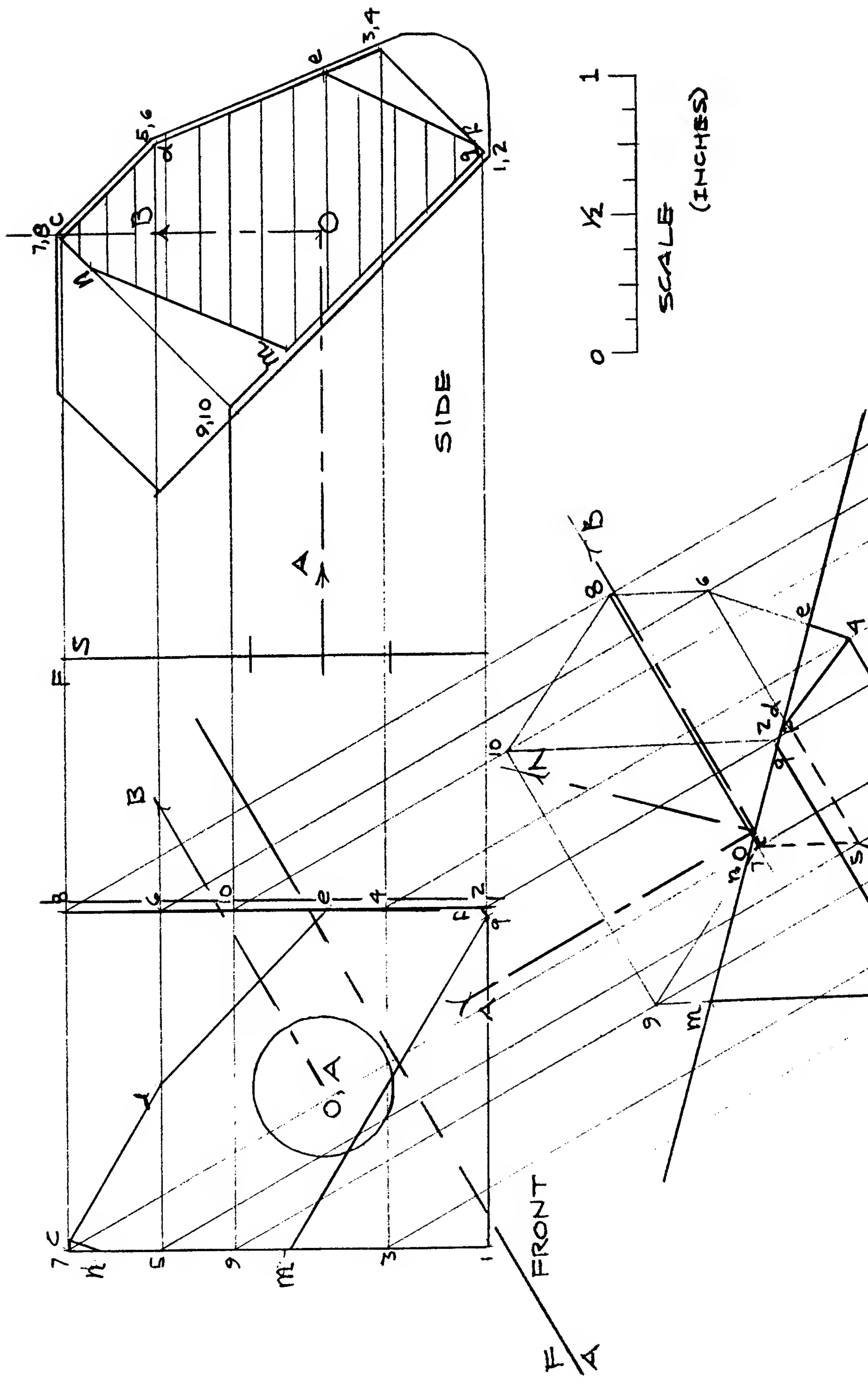


EXHIBIT T-3

ALTERNATE SOLUTION

(NOT RECOMMENDED)

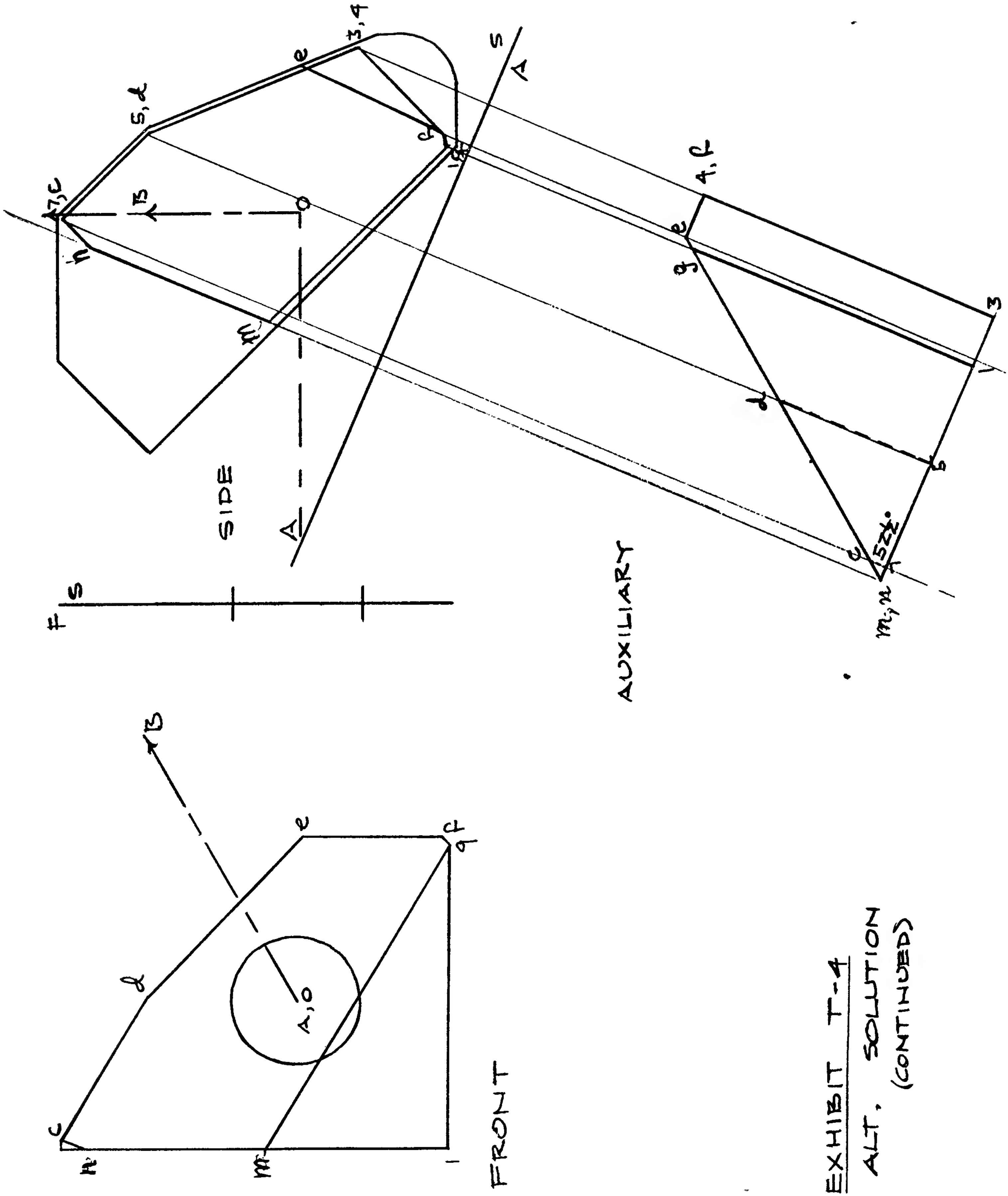


EXHIBIT T-4
ALT. SOLUTION
(CONTINUED)

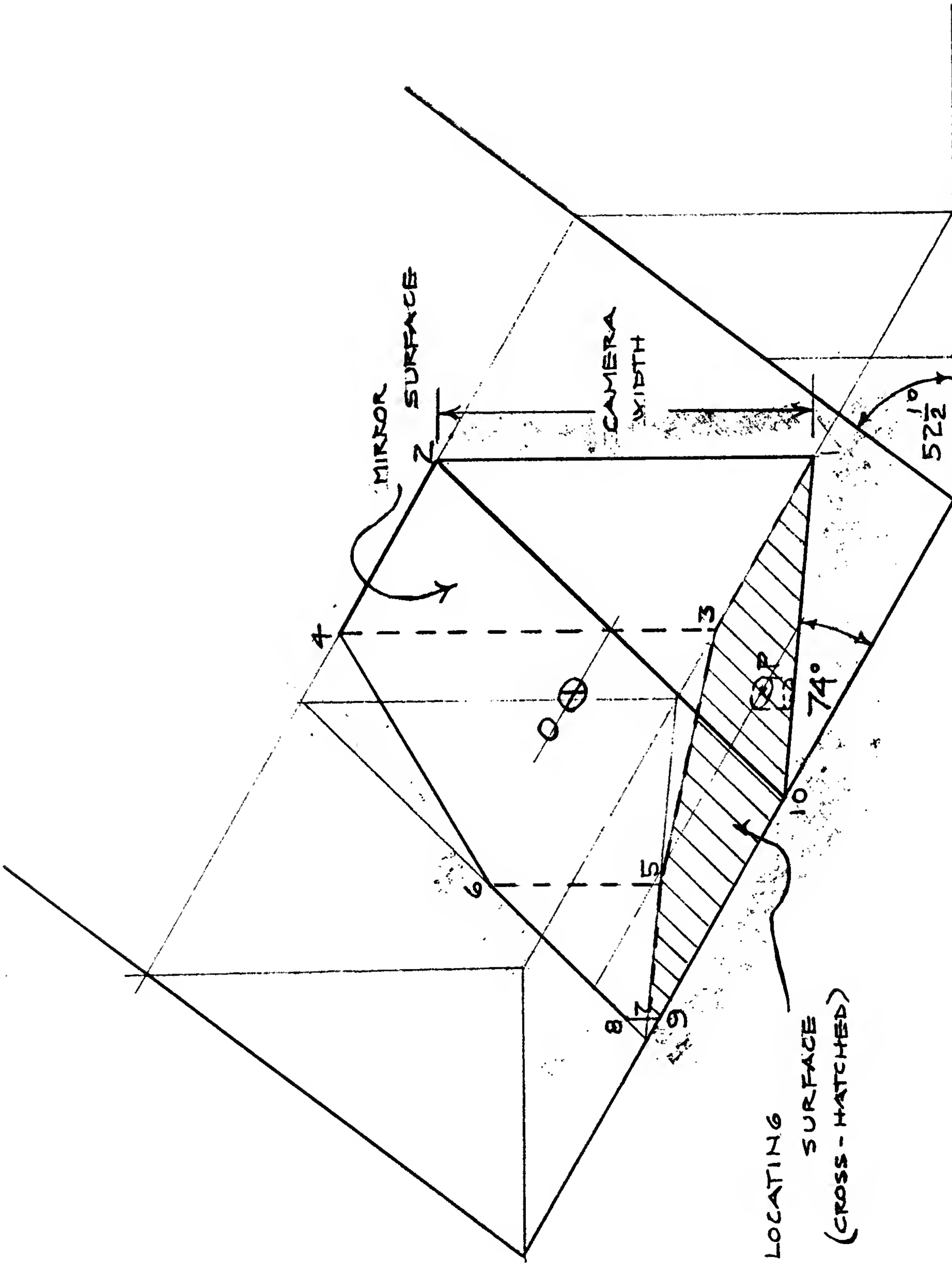


EXHIBIT T-5

OBLIQUE OF BLOCK CUT FROM $52\frac{1}{2}°$ WEDGE.